# Wind Analysis And Comparative Study of High Rise Building Having Diagrid And Outrigger Structural System By Gust Factor Approach

**Deepak P Hittalmani[1], Basavaraj M Gudadappanavar[2],Dr.Mahesh S Patil[3]**
[1]Dept of Civil Engineering
[2]Asst. Professor, Dept of Civil Engineering
[3]HOD, Dept of Civil Engineering
[1, 2, 3] SDMCET, Dharwad

***Abstract-*** *Advances in construction technology, materials, structural systems and analytical methods for analysis and design facilitated the growth of high rise buildings. Structural design of high rise buildings is governed by lateral loads due to wind or earthquake. Recently diagrid structural system is adopted in tall buildings due to its structural efficiency and flexibility in architectural planning. Diagrid structures generally do not require core because lateral shear can be carried by the diagonals on the periphery of building. This paper presents Analysis and design of 30 storey diagrid steel building is presented. A regular floor plan of 18 m × 18 m size is considered. ETABS software is used for modelling and analysis of structural members. All structural members are designed as per IS 800:2007 considering all load combinations. Dynamic along wind and across wind are considered for analysis and design of the structure. Load distribution in diagrid system is also studied for 30 storey building. Similarly, analysis and design of 30storey diagrid structures is carried out. Comparison of analysis results in terms of time period, top storey displacement and inter-storey drift is presented in this paper.*

***Keywords***- Diagrid structural system, Outrigger structural system, ETABS, Storey drift, Storey displacement, Gust factor Approach.

## I. INTRODUCTION

High rise structures are preferable these days, due to population explosion and availability of limited space. Thus influencing the residential development of city. High-rise buildings became possible with invention of the elevator (lift) and less expensive, more abundant building material.

Structural analysis and designing of high rise building becomes challenging due to lateral loads induced by earth quake or wind pressure. Recently, Diagrid structural system is widely adopted for tall steel buildings due to its structural efficiency and aesthetic potential of the system.

## II. METHODOLOGY

The methodology adopted is as given below:

1. Literature study
2. Modeling of Diagrid and Outriggers Structures for different number of stories in ETABS SOFTWARE.
3. Optimizing angle of inclination for diagrid structure and position of outrigger.
4. Parametric Study of Different Parameters influencing the Stability of the structure.

**1. Structural configuration:**

- Count of stories : 30 Stories
- Storey height : 3.6 m
- Total structure height: 108 m
- Dimension of plan: 18 m x 18 m

**2. Material Properties:**

- Grade of Concrete: M30
- Grade of steel reinforcement: Fe500
- Grade of steel sections: Fe345

**3. Structural Parameter:**

- Floor level Column :1000 mm x 1000 mm (steel column) and :450 mm x 450 mm (concrete column)
- Ground level column:1000 mm x 1000 mm (concrete column)
- Floor level Beam :ISMB-600, ISWB-600 (for diagrid structure):ISMB-400, ISMB-500, ISWB-600 (For outrigger structure)
- Ground level Beam:230 mm x 600 mm, 230 mm x 450 mm (For diagrid and outrigger structure)
- Slab thickness: 130 mm

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- Diagrid section: 475 mm Pipe sections with 25 mm thickness
- Outrigger beam: 2-ISA 200 mm x 200 mm x 25 mm (Double angle section)
- Outrigger belt truss:2-ISA 200 mm x 200 mm x 25 mm
  (Double angle section)
- Core wall thickness : 450 mm
- Wall thickness : 230 mm

### III. MODELLING OF DIAGRID:

Diagrid is modelled in Etabs software as per the specifications of building mentioned above.

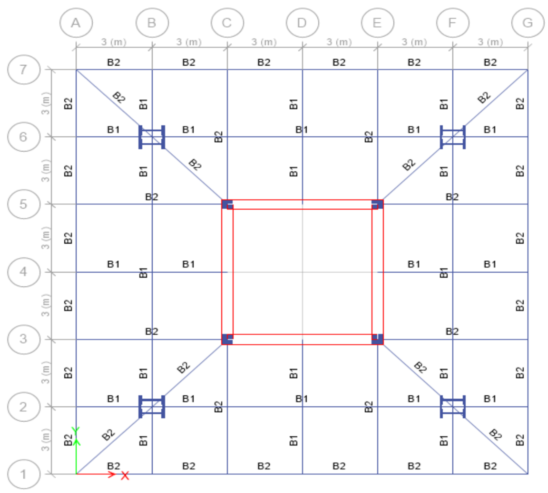



**Fig: Plan of diagrid building**

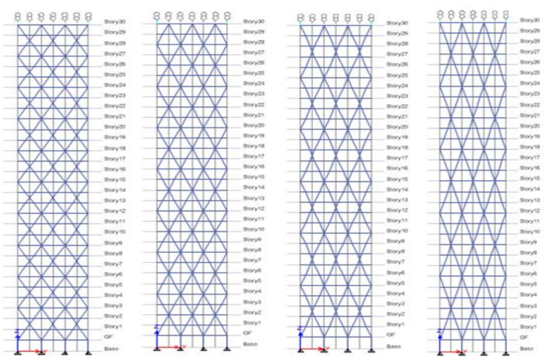


**Fig: 3-storey, 4-storey, 5-storey, 6-storey diagrid module.**

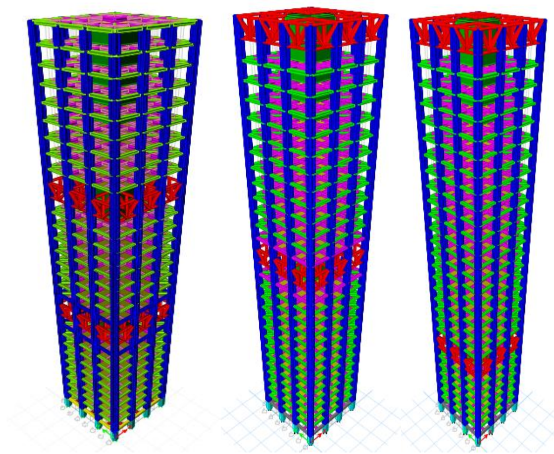


**Fig:1.Two outriggers @ 0.33 and 0.66 height of building, 2.Two outriggers @ Top and 0.5 height of building, 3.Two outriggers @ Top and 0.75 height of building.**

#### 1. Load Assigning on Structure

The loads considered for the following study as per IS codes are given below.

#### 2. Dead Load

- Dead load on floor: 3.25 kN/m²
- Floor finish : 1.0 kN/m²
- Wall load: 0.23 x (3.6-0.6) x 20= 13.8 kN/m
- Parapet wall load : 0.23 x 1 x 20= 4.6 kN/m

#### 3.Live Load

- Live load on floor: 3.5 kN/m²
- Live load on roof : 1.5 kN/m²

#### 4. Wind Load

The lateral loads to be applied on the buildings are based on the Indian standard IS-875-Part 3: 1987

#### 5. Wind Data

- Wind zone: 4
- Basic wind speed ($V_b$) : 50 m/s
- Terrain category : 3
- Class of structure : A (since maximum dimension < 20 m)
- Life of structure : 50 years.

$$\text{Aspect ratio} = \frac{108}{18} = 6 > 5$$

$$\text{Time period (T)} = \frac{0.09 \times 108}{\sqrt{18}} = 2.29 \text{ Sec}$$

$$\text{Frequency (f)} = \frac{1}{2.29} = 0.436 \text{ Hz} < 1Hz$$

Hence Dynamic analysis is necessary.

Gust factor method is the only method of determining load along wind or drag load presented in IS: 875 (Part-3)-1987. In case of wind load under dynamic effects the use of Gust factor method is suggested by code.

## IV. LOAD COMBINATION

The load combinations taken are as shown below:

1. 1.5(Dead Load + Live Load)
2. 1.2(Dead Load + Live Load + Wind Load)
3. 1.2(Dead Load + Live Load – Wind Load)
4. 1.2(Dead Load + Live Load)
5. 1.5(Dead Load + Wind Load)
6. 1.5(Dead Load – Wind Load)

## V. ASSESSMENT AND COMPARISON OF BUILDING PERFORMANCE:

Performance of the building is compared in terms of displacement at top storey , Axial force and Steel consumption.

## VI. RESULTS AND DISCUSSION

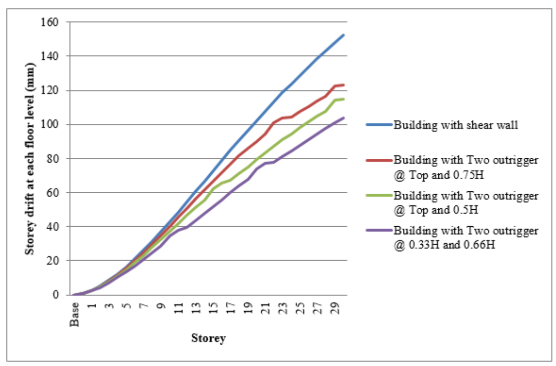
The following results were observed after the complete analysis of the modelled structure. The results of storey drift, storey displacement and storey forces are graphically represented.

**Table Storey displacement at top of building having two outriggers at different locations.**

| Structural systems | Top Storey displacement (mm) |
|---|---|
| Building with shear wall | 152.251 |
| Two outrigger @ Top and 0.75 Height of building | 122.978 |
| Two outrigger @ Top and 0.5 Height of building | 114.646 |
| Two outrigger @ 0.33 and 0.66 Height of building | 103.968 |

**Table Storey displacement at each floor level for building having two outriggers at different locations.**

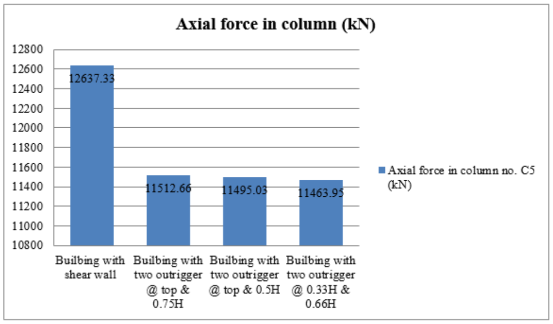
| Storey | Building with shear wall | Building with two outrigger | | |
|---|---|---|---|---|
| | | @ Top and 0.75H | @ Top and 0.5H | @ 0.33H and 0.66H |
| | Mm | Mm | Mm | Mm |
| Storey30 | 152.251 | 122.978 | 114.646 | 103.968 |
| Storey29 | 147.699 | 122.437 | 113.995 | 100.807 |
| Storey28 | 143.071 | 116.267 | 107.598 | 97.606 |
| Storey27 | 138.353 | 113.449 | 104.547 | 94.364 |
| Storey26 | 133.539 | 110.483 | 101.321 | 91.078 |
| Storey25 | 128.617 | 107.399 | 97.951 | 87.749 |
| Storey24 | 123.575 | 104.194 | 94.442 | 84.382 |
| Storey23 | 118.407 | 103.924 | 90.804 | 80.987 |
| Storey22 | 113.109 | 101.018 | 87.048 | 77.568 |
| Storey21 | 107.681 | 94.192 | 83.191 | 76.936 |
| Storey20 | 102.128 | 90.165 | 79.251 | 74.066 |
| Storey19 | 96.455 | 85.887 | 75.251 | 67.586 |
| Storey18 | 90.674 | 81.371 | 71.218 | 63.785 |
| Storey17 | 84.798 | 76.639 | 67.173 | 59.862 |
| Storey16 | 78.843 | 71.72 | 65.806 | 55.839 |
| Storey15 | 72.829 | 66.644 | 62.517 | 51.754 |
| Storey14 | 66.78 | 61.442 | 55.542 | 47.649 |
| Storey13 | 60.723 | 56.149 | 51.112 | 43.569 |
| Storey12 | 54.687 | 50.802 | 46.545 | 39.552 |
| Storey11 | 48.708 | 45.441 | 41.88 | 37.868 |
| Storey10 | 42.823 | 40.11 | 37.167 | 34.847 |
| Storey9 | 37.075 | 34.856 | 32.458 | 28.687 |
| Storey8 | 31.511 | 29.729 | 27.81 | 24.78 |
| Storey7 | 26.182 | 24.785 | 23.282 | 20.91 |
| Storey6 | 21.144 | 20.082 | 18.939 | 17.133 |
| Storey5 | 16.461 | 15.685 | 14.847 | 13.523 |
| Storey4 | 12.201 | 11.663 | 11.079 | 10.157 |
| Storey3 | 8.445 | 8.091 | 7.713 | 7.117 |
| Storey2 | 5.278 | 5.05 | 4.832 | 4.488 |
| Storey1 | 2.769 | 2.623 | 2.521 | 2.359 |
| GF | 0.976 | 0.952 | 0.92 | 0.869 |
| Base | 0 | 0 | 0 | 0 |




**Graph: Outriggers at 2 different locations having storey displacement at each floor Vs Number of storey.**

**Table: For two outriggers at different locations the Axial force (kN) developed in column of building.**

| Structural systems | column no. 5 Axial force (kN) |
|---|---|
| Building without outrigger | 12637.33 |
| 2 outrigger at top & 0.5H | 11495.03 |
| 2 outrigger at top & 0.75H | 11512.66 |
| 2 outrigger at 0.33H & 0.66H | 11463.95 |



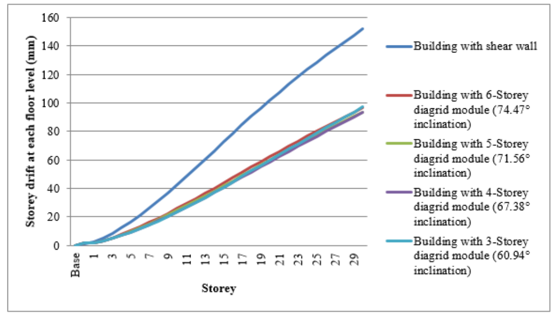

**Graph: Building having two outriggers at different locations Axial force (kN) in column.**

**Table: Displacement at top storey (mm) of building having different storey diagrid modules.**

| Structural systems | Top Storey displacement (mm) |
|---|---|
| Shear wall building | 152.251 |
| Building with 6-Storey diagrid module (74.47° inclination) | 96.63 |
| Building with 5-Storey diagrid module (71.56° inclination) | 93.812 |
| Building with 4-Storey diagrid module (67.38° inclination) | 93.72 |
| Building with 3-Storey diagrid module (60.94° inclination) | 97.355 |

**Table: Storey displacement at each floor level for building with different diagrid module.**

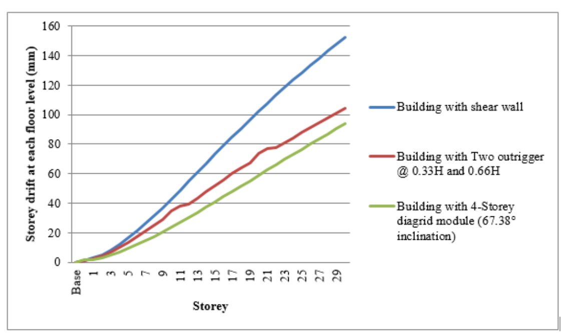
| Storey | Building with shear wall | Building with 6-Storey diagrid module (74.47° inclination) | Building with 5-Storey diagrid module (71.56° inclination) | Building with 4-Storey diagrid module (67.38° inclination) | Building with 3-Storey diagrid module (60.94° inclination) |
|---|---|---|---|---|---|
| | mm | mm | Mm | mm | Mm |
| Storey30 | 152.251 | 96.63 | 93.812 | 93.72 | 97.355 |
| Storey29 | 147.699 | 93.412 | 90.595 | 90.369 | 93.727 |
| Storey28 | 143.071 | 90.161 | 87.348 | 86.99 | 90.069 |
| Storey27 | 138.353 | 86.87 | 84.067 | 83.583 | 86.387 |
| Storey26 | 133.539 | 83.54 | 80.744 | 80.145 | 82.681 |
| Storey25 | 128.617 | 80.157 | 77.376 | 76.672 | 78.946 |
| Storey24 | 123.575 | 76.72 | 73.975 | 73.167 | 75.186 |
| Storey23 | 118.407 | 73.238 | 70.529 | 69.627 | 71.403 |
| Storey22 | 113.109 | 69.703 | 67.043 | 66.06 | 67.6 |
| Storey21 | 107.681 | 66.12 | 63.52 | 62.469 | 63.786 |
| Storey20 | 102.128 | 62.51 | 59.964 | 58.864 | 59.959 |
| Storey19 | 96.455 | 58.86 | 56.388 | 55.234 | 56.134 |
| Storey18 | 90.674 | 55.177 | 52.792 | 51.605 | 52.323 |
| Storey17 | 84.798 | 51.471 | 49.191 | 47.985 | 48.518 |
| Storey16 | 78.843 | 47.751 | 45.594 | 44.387 | 44.748 |
| Storey15 | 72.829 | 44.032 | 42.003 | 40.786 | 41.026 |
| Storey14 | 66.78 | 40.349 | 38.429 | 37.232 | 37.335 |
| Storey13 | 60.723 | 36.691 | 34.887 | 33.737 | 33.721 |
| Storey12 | 54.687 | 33.065 | 31.403 | 30.319 | 30.207 |
| Storey11 | 48.708 | 29.472 | 27.992 | 26.928 | 26.745 |
| Storey10 | 42.823 | 25.948 | 24.656 | 23.647 | 23.416 |
| Storey9 | 37.075 | 22.523 | 21.394 | 20.497 | 20.25 |
| Storey8 | 31.511 | 19.251 | 18.249 | 17.525 | 17.161 |
| Storey7 | 26.182 | 16.121 | 15.26 | 14.566 | 14.276 |
| Storey6 | 21.144 | 13.149 | 12.452 | 11.831 | 11.625 |
| Storey5 | 16.461 | 10.317 | 9.829 | 9.327 | 9.084 |
| Storey4 | 12.201 | 7.713 | 7.368 | 7.195 | 6.829 |
| Storey3 | 8.445 | 5.393 | 5.166 | 4.966 | 4.999 |
| Storey2 | 5.278 | 3.414 | 3.28 | 3.199 | 3.1 |
| Storey1 | 2.769 | 1.832 | 1.77 | 1.796 | 1.762 |
| GF | 0.976 | 1.978 | 1.931 | 1.883 | 1.785 |
| Base | 0 | 0 | 0 | 0 | 0 |




**Graph: Displacement for storey at every floor level for building having different diagrid modules.**

**Table: Top storey displacement for Building with 4-Storey diagrid module (67.38°), Building with Two outriggers @ 0.33H and 0.66H, and building with shear wall**

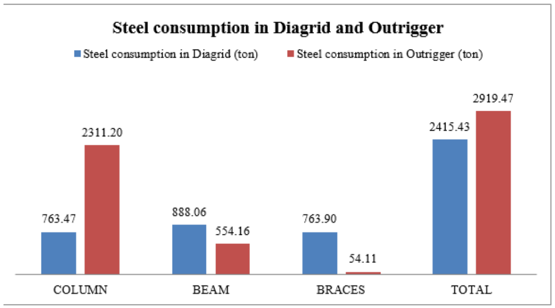
| Storey | Building with 4-Storey diagrid module (67.38° inclination) | Building with two outrigger @ 0.33H and 0.66H | Building with shear wall |
|---|---|---|---|
| | Mm | mm | mm |
| Storey30 | 93.72 | 103.968 | 152.251 |
| Storey29 | 90.369 | 100.807 | 147.699 |
| Storey28 | 86.99 | 97.606 | 143.071 |
| Storey27 | 83.583 | 94.364 | 138.353 |
| Storey26 | 80.145 | 91.078 | 133.539 |
| Storey25 | 76.672 | 87.749 | 128.617 |
| Storey24 | 73.167 | 84.382 | 123.575 |
| Storey23 | 69.627 | 80.987 | 118.407 |
| Storey22 | 66.06 | 77.568 | 113.109 |
| Storey21 | 62.469 | 76.936 | 107.681 |
| Storey20 | 58.864 | 74.066 | 102.128 |
| Storey19 | 55.234 | 67.586 | 96.455 |
| Storey18 | 51.605 | 63.785 | 90.674 |
| Storey17 | 47.985 | 59.862 | 84.798 |
| Storey16 | 44.387 | 55.839 | 78.843 |
| Storey15 | 40.786 | 51.754 | 72.829 |
| Storey14 | 37.232 | 47.649 | 66.78 |
| Storey13 | 33.737 | 43.569 | 60.723 |
| Storey12 | 30.319 | 39.552 | 54.687 |
| Storey11 | 26.928 | 37.868 | 48.708 |
| Storey10 | 23.647 | 34.847 | 42.823 |
| Storey9 | 20.497 | 28.687 | 37.075 |
| Storey8 | 17.525 | 24.78 | 31.511 |
| Storey7 | 14.566 | 20.91 | 26.182 |
| Storey6 | 11.831 | 17.133 | 21.144 |
| Storey5 | 9.327 | 13.523 | 16.461 |
| Storey4 | 7.195 | 10.157 | 12.201 |
| Storey3 | 4.966 | 7.117 | 8.445 |
| Storey2 | 3.199 | 4.488 | 5.278 |
| Storey1 | 1.796 | 2.359 | 2.769 |
| GF | 1.883 | 0.869 | 0.976 |
| Base | 0 | 0 | 0 |



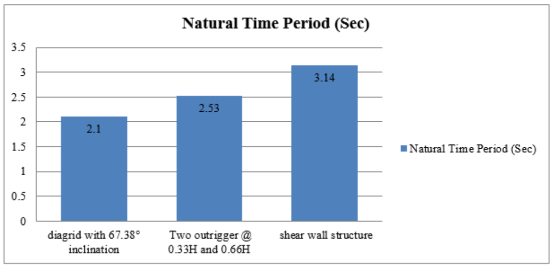

**Graph: Top storey displacement for Building with 4-Storey diagrid module (67.38°), Building with two outriggers @ 0.33H and 0.66H, and building with shear wall.**

**Table: Steel material consumption for diagrid and outrigger structural system.**

| Material Consumption | Steel consumption in Diagrid (ton) | Steel consumption in Outrigger (ton) |
|---|---|---|
| Column | 763.47 | 2311.20 |
| Beam | 888.06 | 554.16 |
| Braces | 763.90 | 54.11 |
| Total | **2415.43** | **2919.47** |




**Graph: steel material consumption for diagrid and outrigger building with variations.**




**Graph: Natural time period for diagrid, outrigger and shear wall structure.**

## VII. CONCLUSION

The present paper is an effort to investigate the behaviour of diagrid system and outrigger system in high rise building with 108m height subjected to trapezoidal distribution of wind loads. The conclusions depending on the analysis results are as follows:

1. Introduction of outrigger with belt truss system and perimeter diagrid system in multi storey high rise buildings highly improves the structural stiffness and makes the structural system effective and efficient under lateral load as well and also reduces the lateral displacement.
2. The displacement at top storey of Building with 4-Storey diagrid module (inclined at 67.38°) decreases by 10 % compared to Building having 2 outriggers @ 0.33 height and 0.66 height. Thereafter, we get the conclusion that for perimeter diagrid system of normal system.
3. With provision of the outrigger the stresses in the columns are decreased when compared to building without an outrigger system. With provision of outriggers, the forces are uniformly distributed and therefore, there is reduction in column axial forces.
4. The percentage increase in steel material for outrigger structure is 17% more than diagrid structure. Therefore, we can conclude that for high rise buildings, provision of diagrid structural system will be economical.
5. The paper shows that the performance of diagrid and outrigger structural systems is considerably affected by the angle of inclination of diagonal members and optimum location of outrigger system respectively. Therefore, from analysis results, we can conclude that the angle of inclination for diagrid structure is optimum at 67.38° for 4-storey diagrid module and location of outrigger structure is optimum at 0.33 height and 0.66 height that is 1/3rd and 2/3rd of height to which corresponding top storey displacement is obtained to be less.
6. The time period of structures with diagrid is lesser when compared to outrigger structure due to perimetral diagonal member the stiffness of diagrid structure increases (2.1 Sec). Therefore, we can conclude that, the diagrid structural system is stiffer than the outrigger and shear wall structural system.
7. Multi storey high rise buildings with perimeter diagrid system can be provided for structural effectiveness and architectural feasibility for plan. When compared to conventional structure, diagrid structure consist of inclined column (i.e. diagonal) at the perimeter of building. Hence diagrid structure provides more feasible system for architectural plan and also higher structural efficiency for high-rise buildings can be achieved.

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